FRONT COVER

Developing a Methodology for Elaborating a Pulsed Optical Safety Area for High Power Laser Diodes

Final Technical Report
By

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14. ABSTRACT
A methodology to determine the safety area of pulsed operation of laser diodes is established. On its bases lifetime of high power diode is measured. Under 10 times higher currents and 1 MHz operation frequency the expected life time is more than 5 000 h. Further development of the driving circuits will allow accurate distance for 3D scanning lidar to be measured with accuracy of few cm.

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F I N A L   R E P O R T

"Developing a methodology for elaborating a Pulsed Optical Safety Area
For High Power Laser Diodes"

Principle Investigator: **Plamen Yankov**
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Summary

The laser diodes are efficient sources of optical radiation. The maximum optical peak power depends on the pulse duration of the driving current pulse - reducing the pulse duration the safety peak power is increased. The aim of the study is to elaborate a methodology to determine the safety operation area of the high power laser diodes designed for CW operation. Using this methodology, the designer of certain laser devices may exploit the maximum of the laser diode under pulsed operation. The methodology is based on measuring the dynamic behavior of the junction temperature and the dependence of the efficiency of the laser action versus the peak current for rectangular pulses with parameter the pulse duration. The maximum peak current is determined as a 10% "walk off " from the linearity between peak current / optical peak power for every pulse duration. The curve (max. peak current) / (pulse duration) is plotted. Knowing the maximum peak current, the repetition frequency for a given pulse duration may be calculated for a given average power.

Key words : High Power Laser Diodes

Contents of the Report :

1. Introduction.

The high conversion efficiency of the high power laser diodes makes them an attractive component for many high-power applications, such as material processing, free-space communications, solid state materials pumping /1 – 3 /. Most of the application schemes require short laser pulses duration and high repetition rate lasers. This is achieved by pumping solid state lasers (DPSS). In this case the overall efficiency is reduced. Another important feature for a field instruments is the access time – there is a certain time to reach the laser diode temperature for matching the absorption and emission wavelengths. The last reduce strongly the application of the DPSS lasers, especially for laser guiding missiles, field range finders. For many applications the direct use of the laser diodes is possible. As it has been shown / 4 , 5 / optical pulses with rise / fall times of 20 ns are developed at drive currents x 100 A . The most important feature for those applications is the life time of the laser diode and the maximum drive currents.

In recent years, many groups optimized the design of laser arrays to decrease the thermal load and to maximize the output power in different operating regimes / 6 and literature cited there /. It was shown that arrays with high emitter density and large fill factors are preferred for short-pulse high peak power operation, while arrays with low emitter density and small fill factor are better suited for long-pulse, high average power operation.

The widely used empirical approach for the laser diode life time is to place several diodes (at least 10 pcs.) and to follow the life time / 7 , 8 /. In the case of pulsed operation the number of diodes under tests should be multiplied because two independent parameters, peak current and pulse repetition rate, have to be included, which makes such study difficult . At low repetition rate and long pulses (several Hz , ms) the methodology is to follow the junction temperature and the waveform of the optical pulses / 9 , 10 /. .

The purpose of this study is to develop a practical engineering methodology for elaborating the maximum parameters – peak current, repetition rate versus the pulse duration for laser diodes designed for CW operation. In comparison with the pulsed injection diodes, the CW diodes allow higher average powers, hence higher repetition rates to be achieved.

A second feature of the study is to compare diodes from different producers, using different chips production and assembling technologies.

2. Experimental Set up.

The experimental set up is shown on Fig.1 .

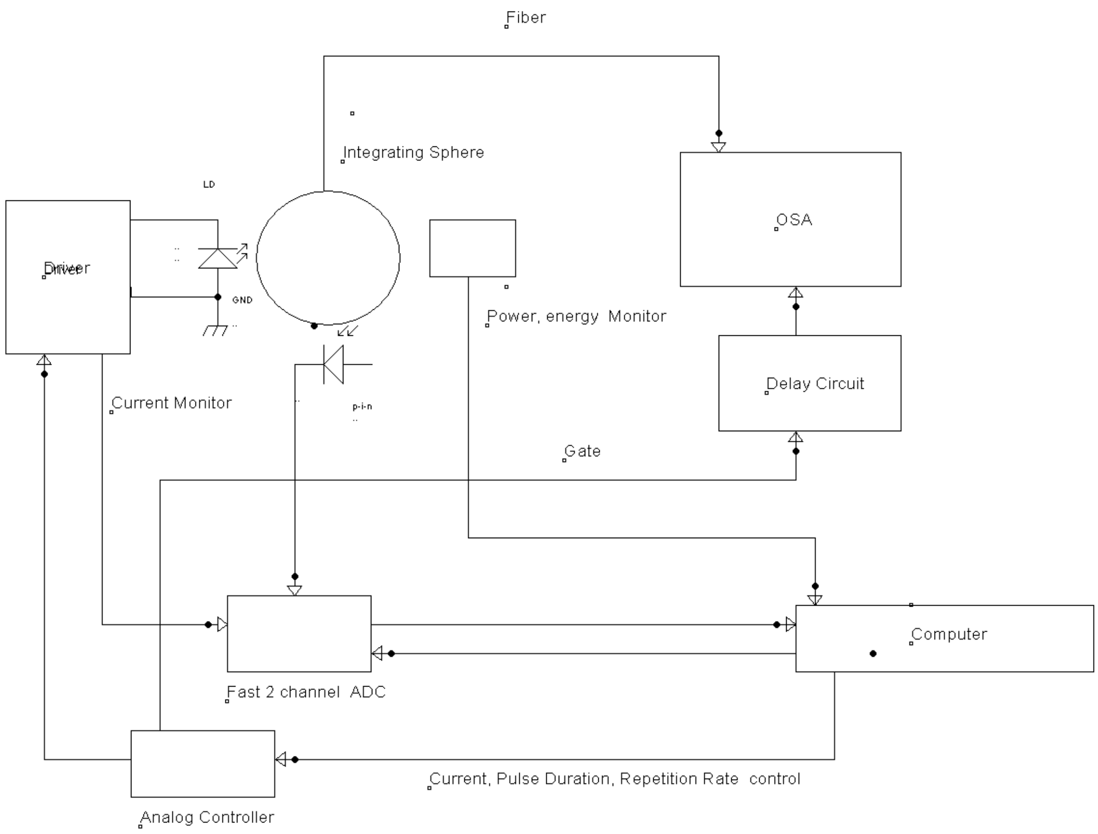


Fig.1

The laser diode under test is mounted on an appropriate heat sink. Most of high power laser diodes are p-side down , and the "anode" is grounded. The diode case temperature is controlled by a water/to/water thermo controller with 0.5 deg. C accuracy from 10 to 90 deg. C. The heat sink is placed inside a thermo isolated box with an exit for the optical radiation towards a calibrated integrating sphere. Thus the total radiation is measured simultaneously by a power meter PM , energy meter EM , fast p-i-n photodiode PD. A fiber coupled optical multi channel spectrum analyzer OSA is connected. The micro channel amplifier of the OSA is gated by a delayed 100 ns pulse, synchronized with the driving pulse. The laser diode is driven by different power supplies PS, depending on the required repetition rate and maximum average power. The information for the current pulse is taken from an non inductive temperature stabilized shunt resistor. The signals from the shunt resistor and photo diode are digitized by a fast 2 channel 14 bit analog tot digital converter ADC. The experiment is controlled through an USB2 interfaced computer PC.

The power supplies are designed according / 11 , 12 , 13 / . Two version power supplies are designed.

2.1. The first version is for high repetition rate and maximum current up to 100 A from DC to 10 MHz.

Following the tradition for small space and high efficiency, a high frequency inverter transforms the input voltage (a 220 V AC mains or 24 V, 48 V input) Fig. 2. After that the transformer output current is rectified. If the inverter is designed in a way that the current through its primary coil is followed as a source for the feedback, then the transformer is designed as a current transformer, and the output current at the secondary coil follows the primary current with the ratio of the transformer. In this case the output voltage is the voltage drop over the laser diode which depends on its structure.

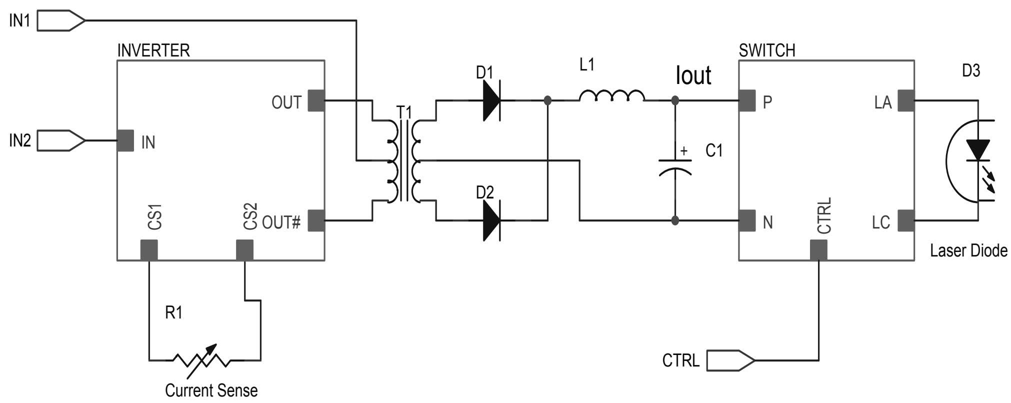


Fig. 2

The efficiency calculated for the output/input power has sense only at the maximum output power. For example the current source may work when the output leads are shortened - output voltage is zero and output power also! From engineering point of view the maximum output voltage for a true current source without load must be at least 10 times higher than the voltage drop over the diode. In the other case the current source becomes a power source and special feedback must be included in order to keep the regulation linear. Unfortunately this is the common case, because, for example, if we have a 100 A linear diode bar with voltage drop (including connecting wires) of 3 V, we have to design a power supply with 3 kW capability! We designed the compromised version with max. 5 V output voltage. A picture of the power supply is shown on fig. 3 . The mechanical and thermal design with only one cooling plate, allows the power supply to be hermetically sealed for harsh environment application.

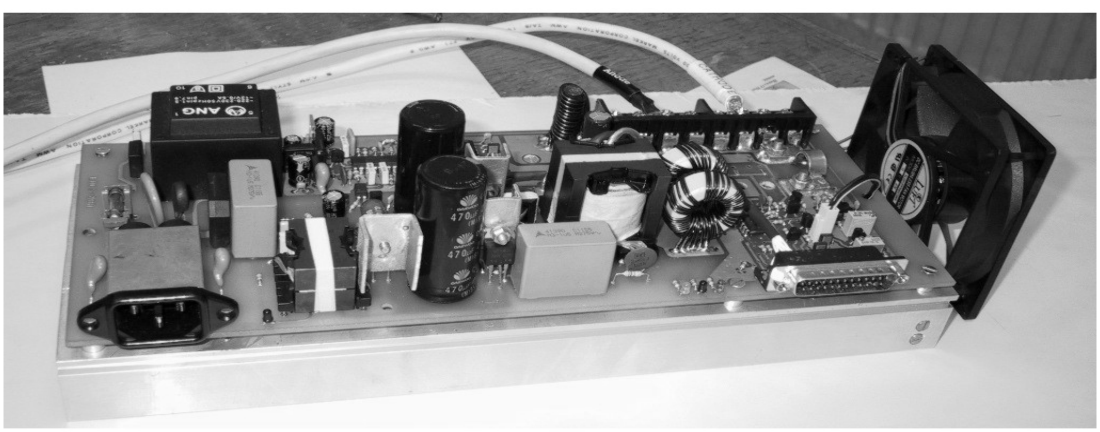


Fig. 3

The big difference between a true current source and a voltage source with current limitation is the output filter. In case when a voltage source is used, the output filter is a capacitor , while in the case when a current source is used, the filter is an inductive. This allows the inductance of the connecting wires between the power supply and laser diode to be included in the total inductance of the output filter and the feedback response time to be close to the inverter switching frequency. In our case the switching frequency is 250 kHz , and the feedback response time is approximately 4 cycles , i.e. 50 kHz. Thus the power supply prevents the laser diode from fast, uncontrolled spikes, arcs from loosed connections and etc..

The switch for the pulse operation is located very close to the laser diode. It is a combination of parallel and serial switching elements / 12, 13 / shown on fig. 4.

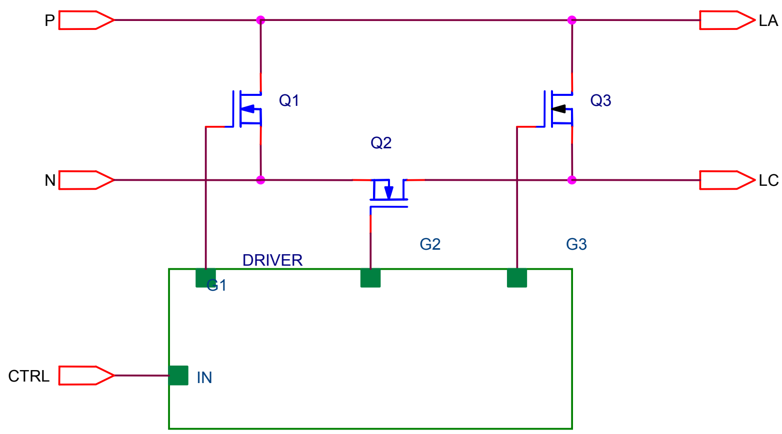


Fig.4

The only inductance is the inductance of the solid leads of the laser diode connected to LA –LC itself, which may be assumed approximately several nH. The parallel and series switching elements are synchronized with appropriate delay between them. The delay is longer than the delay time of the switching MOS transistors. The switching transistors consist of several transistors in parallel. Every transistor is driven by a separate driver. Thus the total inductance is reduced. The parallel transistor Q1 is always “on” and the power supply output current is stabilized. The series transistor Q2 is switched on and the parallel switch Q1 is switched off , and the same already stabilized current is allowed through the laser diode. The laser diode current rise time is determined by the “switch off” time of Q1. Thus, the current from the power supply is not interrupted, during switching on and off. Additionally, the voltage drop over the parallel switch may be chosen close (less) to the voltage drop over the laser diode and $dU= LdI/dt=0$. Switching off the laser diode is in the reverse order – first Q2 is off and Q1 is on. The transistor Q3 is for protection of the laser diode and is switched on for a very short time after the cycle. The restrictions for higher frequencies come from the delay times of the switching elements and the inductance of the circuit Q1 Q2 LD. To reduce this inductance the switch must be very close to the laser diode. For a C mount diode, it is mounted on the same board. In the case of fiber coupled encapsulated laser diode bars, the switch is located inside the bar box Fig.5 .

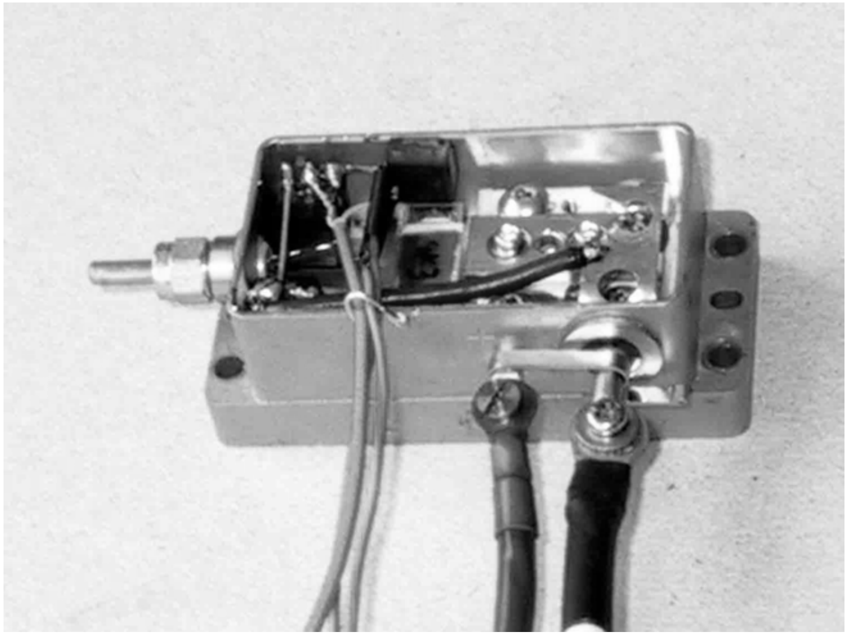


Fig. 5

On Fig.6 the optical pulses at 40 A are shown. It is seen the rise/fall times for 200 ns pulse duration. For this switch version the rise/fall times are 18 ns / 25 ns . It is seen also that the spikes do not exceed 5 %.

The reverse pulse (interrupting the laser emission) with current - 35 A, is shown on Fig. 7 . For 200 ns the laser diode is stopped. This version allows maximum 5 MHz switching frequency for square wave optical pulses at maximum currents 96 A.

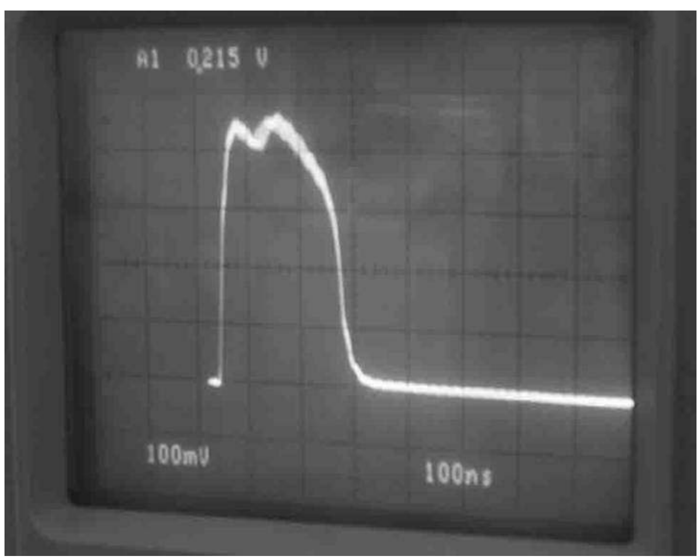


Fig. 6.

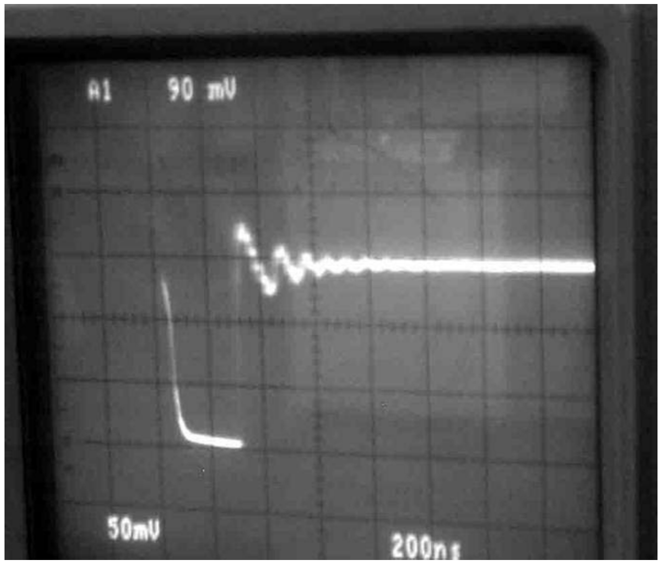


Fig. 7

2.2. The second power supply is for lower repetition rate and lower average currents, but for very high peak currents. The power supply should be designed with an energy storage component (capacitor or inductor) and an average power compared with the power which can be dissipated from the LD. The power supply developed by us enables to obtain x 100 A (maximum 400 A) peak currents for stacks with voltage drops 300 V (100 bars vertically arranged) and current rise / fall times less than 20 ns. The block diagram is shown on Fig. 8. It consists of regulated voltage charger of high capacitor C1 and current limiting shunt resistor Rsh . The switch is similar to the previous but the transistors are controlled in different way.

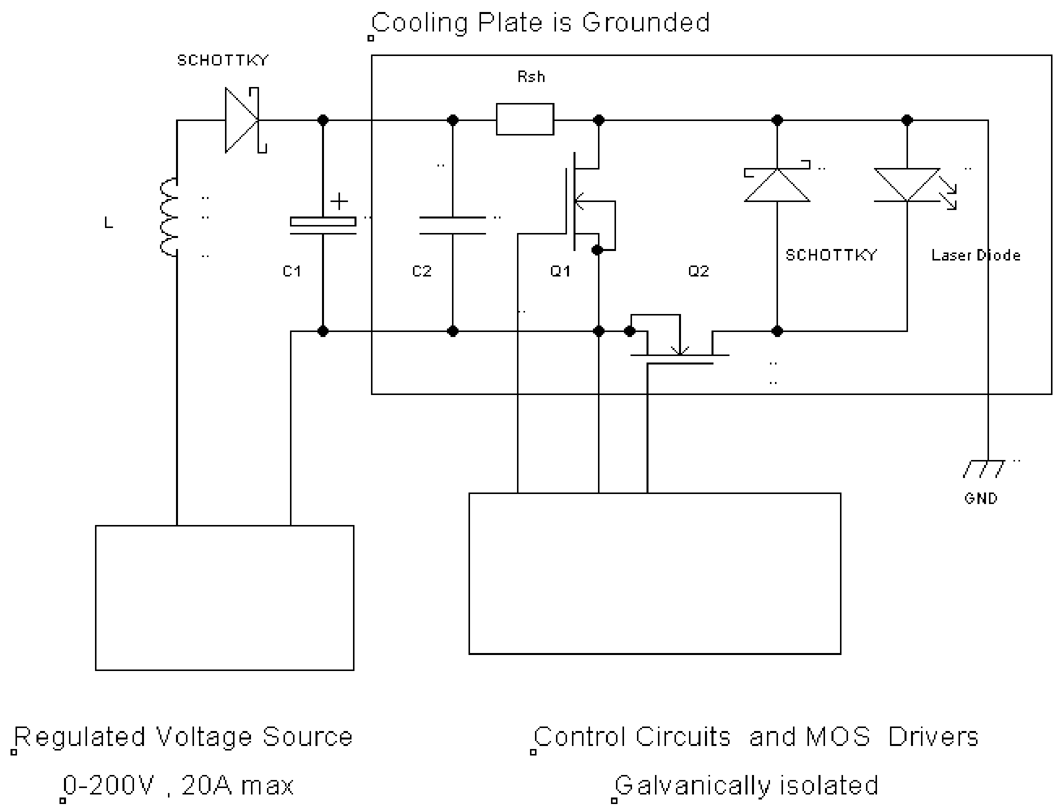


Fig. 8

The capacitor C1 is charged to the desired voltage with high accuracy. Q1 is turned on for an interval, needed for the current to charge the inductor and the connecting wires. Normally this time is in the order of several hundreds ns. The voltage drop over Q1 is much less than the voltage drop of the LD. For this interval the transistor Q1 is calculated according his avalanche parameters (peak current and avalanche energy). During this time interval the switch Q2 is turned on, after a delay from the Q1 turn . Rising of the current through the laser diode occurs when Q1 is turned off. The rise time of the optical pulse is determined from the turn off time of Q1, the inductance of the wires inside the diode and its capacitance. On fig.9 the current through the shunt resistor, which is the total current through Q1 and laser diode, is shown for a time scale of 200 ns per division.

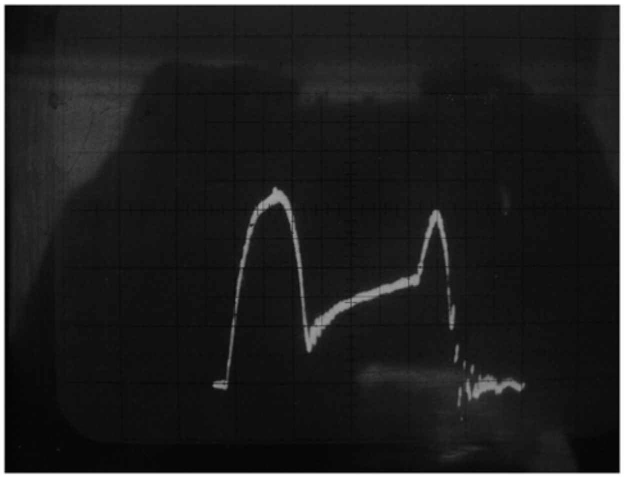


Fig. 9

The delay times are increased for a better picture. It is seen that at the beginning the current is higher (the resistance of Q1 is less), at the maximum of the first spike Q2 is switched on and Q1 is switched off. The current starts through the laser diode. It rise time is the fall time of the first spike. At the end Q1 is switched on for a short period and the current again is higher. The fall time of the current through the laser diode is the fall time of the second spike. The digitized waveform is transferred to the computer, where the spikes are extracted for the laser diode peak current calculation.

On Fig. 10 the 500 ns the optical pulse waveform for 200 A is shown. The time scale is 50 ns / small division. As it is seen, the rise / fall times are below 20 ns and 50 ns . The diode is № 2 - a 40 A laser diode bar from Fig.5. It is seen that the optical pulse do not have spikes more than + / - 5 % from the maximum.

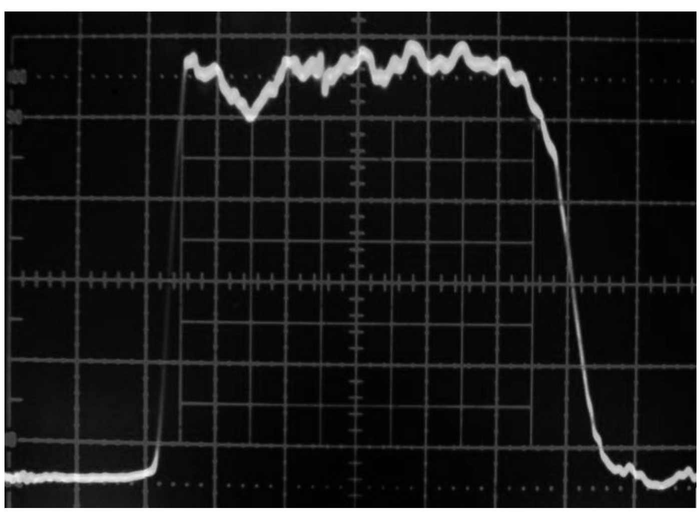


Fig. 10

The maximum pulse duration of this power supply depends on the value of the capacitor C1. In our case it is not more than 1 ms. The maximum average current depends on the power capacity of the shunt resistor and is designed to be 20 A. The shunt resistor value must satisfy the conditions

$\tau = Ld / Rsh$ < current rise time

$Rsh = U c / I$ diode peak

$Rsh >> Rds$

Where Ld is the inductance of the circuit Q1,Q2,LD . Uc is the capacitor C1 voltage , Rds is the open state resistance of the MOS switch. The actual value of Rsh is 0.5 Ω . The estimated inductance L is 10 nH. The power over R1 depends on the laser diode average current and allows 20A max. In this case the diode № 2 may be driven to 50 % duty cycle , i.e. 20 W average power. The resistor is mounted on the laser diode heatsink.

2.3. Thermal transients measuring circuit. The diagram is shown on Fig.11.

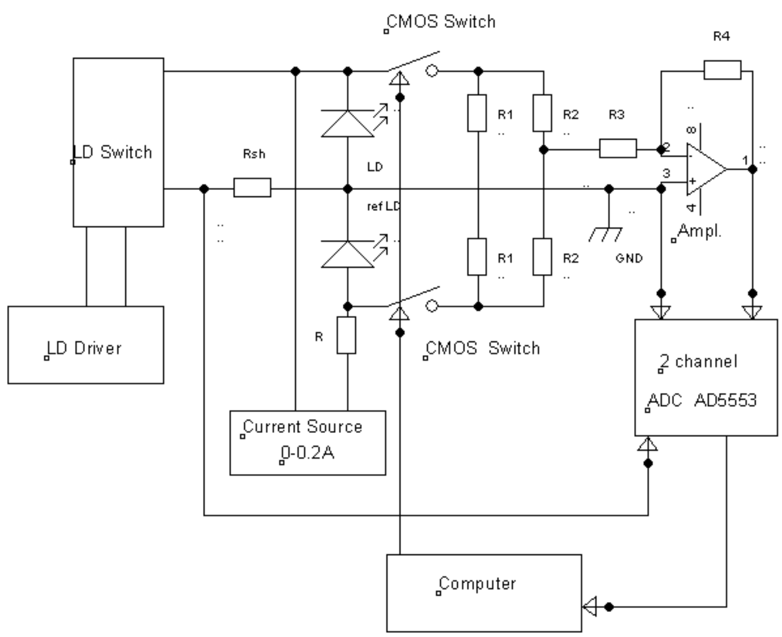


Fig.11

The problems to measure the fast thermal transients come from the very different voltage drops over the laser diode (1.400 V at 0.2A , 1.800 V at 2A , 4 V at 200 A) and the need to measure parts of mV in a noisy surrounding (the noise coming from switching 200A for 20 ns is high). The analog MOS switches are switched on after the high current pulse. We use a differential scheme, where two identical laser diodes are mounted on the same heat sink with the same measuring constant current. Thus the effect from different case temperatures is eliminated. At constant current, the voltage drop versus temperature is measured and a comparison is established / 14 /.

2.4. Maximum peak current determination.

The repetition rate is chosen to be lower than 1 / 10 t , where t is the time constant of the relaxation of the junction thermal transients. The peak current is raised slowly. After reaching the laser threshold and below the maximum DC current , the linear dependence of the efficiency current / optical power is interpolated. The computer remember slope and for every next step it calculates the position of the new value of the peak power. Every value is compared to the predicted value. When a decrease of "walk off" of 5% from the predicted value is observed, the current is increased very slowly till 10% "walk off" is detected. This value is recorded as a maximum peak value for every pulse duration. For the pulse durations shorter than 200 ns (limited from the sample rate of our Analog to Digital Converter) we calculate the peak power from the pulse energy. The graph (pulse duration)/ (maximum peak current) is plotted.

2.5. Choice of laser diodes. The investigated laser diodes have been chosen from the following consideration:

- Only from producers which produce the laser chips and assemble them.
- The diodes are commercial, without any special requirements.
- Every diode is supplied with its individual parameters.
- Different assembling technologies.
- Single transverse mode diodes (C – mount) , conduction cooled laser bars , fiber coupled laser bars.
- The single transverse mode diodes on C-mount are chosen because of their lower inductance. Normally the producers use the same production technology for single chip and bar diodes. Their behavior under pulsed operation is expected to be the same with less current. The single mode laser beam is better collimated with lower divergence. At the moment they are more suitable for future applications. At last – their price is much lower, which enables us to purchase more diodes.

From those points of view the studied laser diodes are :

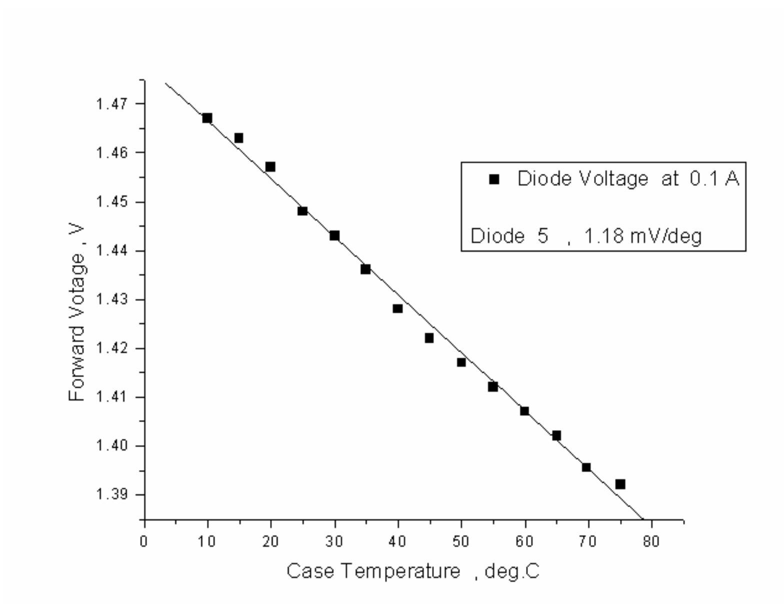
Producer	№	laser Diode	Considerations
Coherent Inc. USA	1. 2.	3W C-mount 40 W Fiber coupled Bar	Al free devices Leading Producer, Army Supplier
Dilas/OSRAM Germany	3.	30W Bar	"Sirilas" Chips
JenOptik Germany	4.	30W Bar	German Leader Attractive price
Bookham Switzerland	5.	7W fiber coupled	The highest Power from single structure
Quintessence Canada	6.	7W C-mount	The highest brightness Army supplier
Inject Russia	7.	20W Bar	Attractive price Army supplier Au / Sn soldering

Remarks:

1. The company nLight (USA) refused to sell their product after receiving the information for the end user. There is only one serious company missing from the list : Newport-SpectraPhysics.
2. The only specifications for pulsed mode is from OSRAM / 15 /.
3. Bookham claims they have special high optical power facets coating
4. Quintessence claims to have the best passivated output facet coating.
5. Inject is not very familiar among the world suppliers, but their assembling capabilities turned our attention. Little is known about their diodes structure – we suppose it is not Al free.

RESULTS.

3. Thermal transients. The high current pulse heats the junction . At the end of the pulse the temperature is decreased by diffusion through the whole heterostructure and after that through the metallic leads to the diode heatsink. We are interested how much is the temperature inside the junction during the pulse. For long pulses (more than 10 μs) the temperature may be measured by the emission peak wavelength / 9 , 16 , 17 / . This method has some uncertainties because the calibration - temperature / wavelength is done under laser emission when the heat from the pumping current can not be neglected and the case temperature is different than the junction one. Under steady state conditions this is a figure of merit for the temperature resistance / 18 /. We choose the electrical method by measuring the voltage drop at constant current. For this we choose small DC current in order to exclude its dependence on the junction temperature and the voltage drop over the metal contacts. Typical graph for diode № 5 at 0.1 A constant current is shown on Fig.11 . It is seen a linear dependence of 1.18 mV / deg.C . On the same figure the graph for diode № 1 is shown. For this diode the linear relationship is 1.39 mV / deg.C. The wavelength for the two diodes is 940 nm and 810 nm respectively.



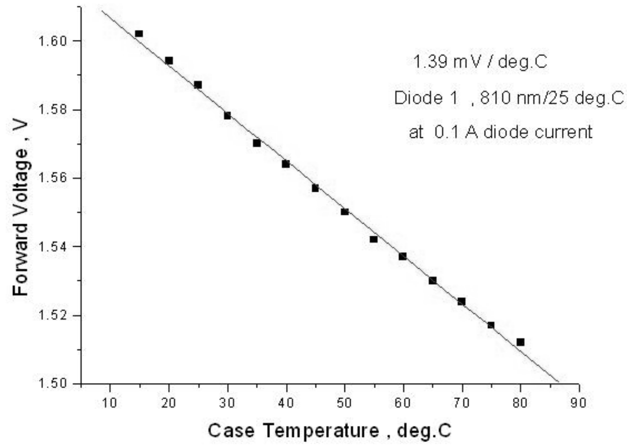


Fig. 11 .

The above relationship is used for calibration.
The voltage waveform of the forward voltage on the diode after the end of the pumping pulse is digitized and interpolated for every pulse duration at the same constant current of 0.100 A.. The waveform is taken after a delay of 200 ns to exclude the EMI noise. A typical graph is shown on Fig. 12 .

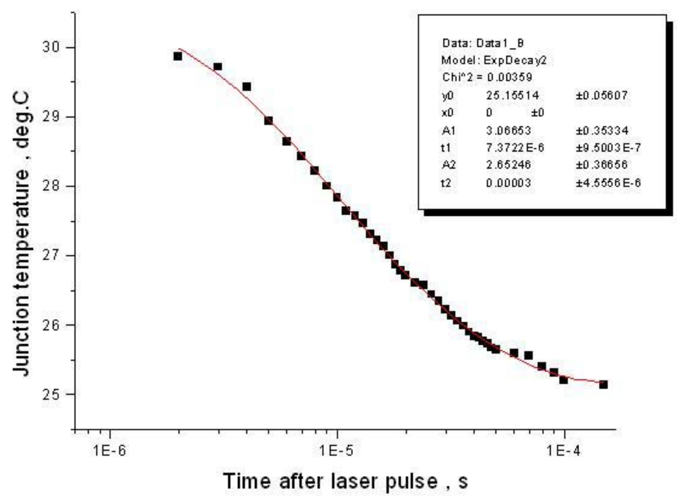


Fig. 12

The conditions are 1 µs , 20 A peak current for the diode № 1 with repetition rate of 1 kHz. As can be seen the curve is fitted by a two exponential solid line.

```
Fit:  y = 25 + A1e^(-(x)/t1) + A2e^(-(x)/t2) :

A1              3.06653
t1              7.37216E-6
A2              2.65246
t2              3.0847E-5
```

The two time constants t1 and t2 represent the temperature diffusion inside the junction and to the leads of the chip towards the heat sink. These constants do not represent the temperature diffusion to the heat sink, which is much slower. The junction temperature is reaching 30 deg. C. at the end of the pulse. This was confirmed by measuring the peak wavelength assuming 0.3 nm per deg. C wavelength shift / 16 / . The wavelength was measured by the 100 ns gated Optical Spectrum Analyzer OSA . Those values correspond to the thermal diffusion coefficients for a structure pointed in / 6 / .

From this graph we determine the maximum repetition rate when every pulse acts as an individual pulse. In other case the average junction temperature is higher and every sequent pulse starts from different base level - similar situation for the GaAs semiconductors / 20 / .

For the same diode the CW dependence of the optical output power versus the case temperature is shown on Fig. 13. The data are taken with pulses with current close to the threshold for the maximum temperature in order to reduce the difference between case and junction temperatures – in our case it is 1.2 A. The pulse duration is 200 ns and repetition rate of 5 kHz. Thus the electrical average power is 2 mW and there is no pulse heating of the structure. We can assume that the junction temperature is the same as the case temperature. It is seen a linear dependence. At 30 deg.C the output power is only 2 to 3 % lower than the power at 25 deg.C. At 80 deg.C the output power is 10% from the 25 deg.C power. The extrapolated curve for 140 deg.C is 80% from the 25 deg.C power.

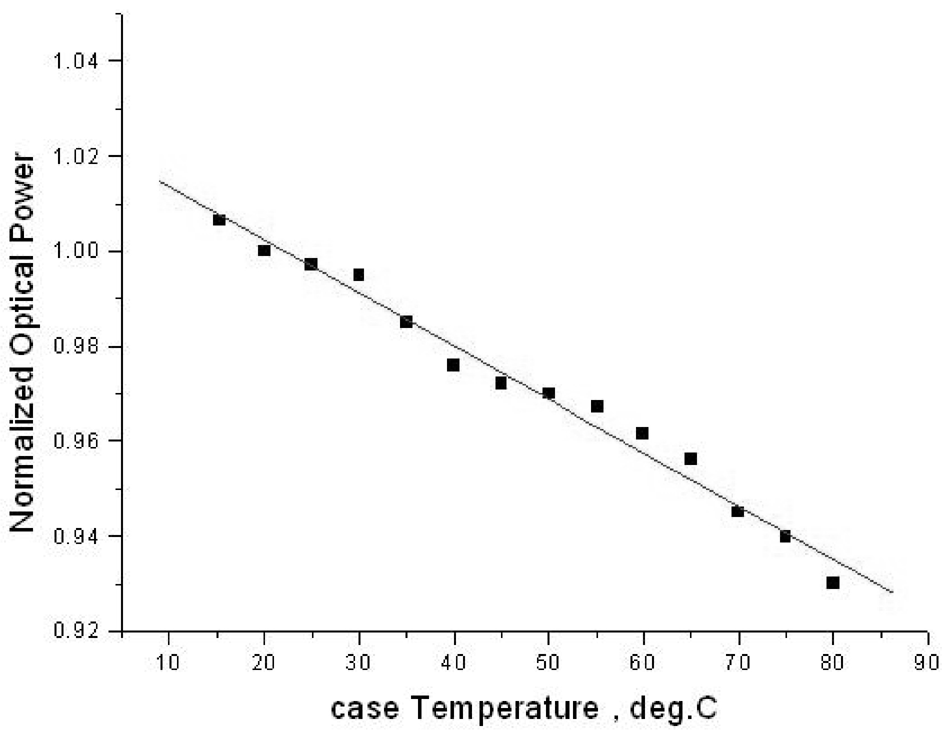


Fig. 13

This assumption is valid, if the laser still generates. This was not measured – our cooling liquid is distilled water. For this temperature and a rectangular shape of the current pulse we can calculate that the moment peak power of the optical pulse at the end of pulse will be 80 % from the starting value.

Assuming linear decrease of the momentary peak power / 9 / , then the total pulse energy decrease will be 5 – 6 % from expected power for 30 deg.C temperature rise. For long pulse duration, longer than 0.1 ms, and lower peak currents, it is possible to digitize the waveforms of the current and optical pulses and to follow their equality. As we see the junction temperature rise will have much more stronger impact on the pulse energies – the optical pulse waveform will not have rectangular form, which we do not observe for short pulse durations. The total heat generated by the electrical pulse, even at very high currents, is much smaller than for long pulses. The area

(Id . t pulse) = 100 A . 100 ns << 20 A .1 ms

compared to the long pulse duration. We conclude that the temperature effect during driving pulse duration do not decrease the optical output peak power.

4. Dependence of the maximum peak current from the pulse duration.

The experiment is carried at constant case temperature and repetition rate not exceeding the maximum, determined from the thermal transients graph . As it was explained, the diode current is raised slowly by steps . For every step the pulse energy is measured and the optical peak power is calculated. The interpolated linear curve is predicted from the first several points after threshold and is "remembered " in the program which controls the current raise . Every next point is compared with the predicted value. The maximum current is determined as a 10 % "walk off " from the linear curve. Typical data are presented on Fig.14 - diode 1 , Fig. 15 – diode 2 , Fig.16 - diode 3 , Fig.17 – diode 5 , Fig.18 - diode 7 . The plotted data are presented for several pulse durations. We have to admit that diode 6 has not been measured, because it failed at 12 A current at 500 ns pulse duration – much below the expected value. Diode 3 showed irreversible failure at the start.

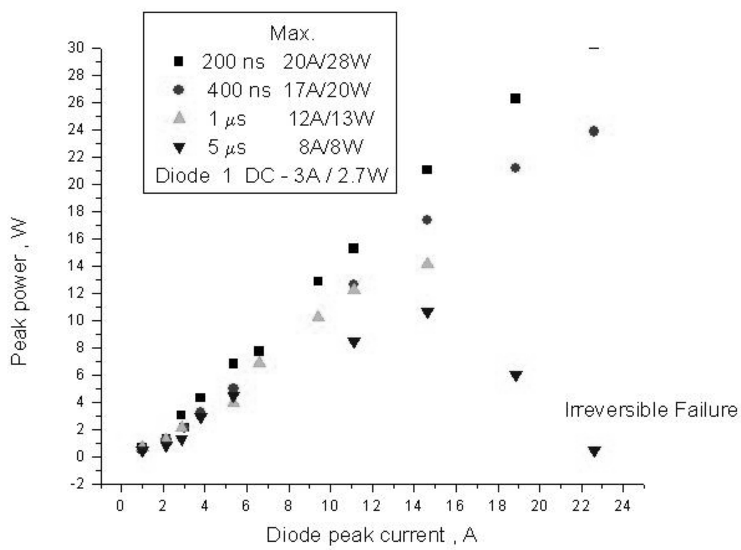


Fig. 14.

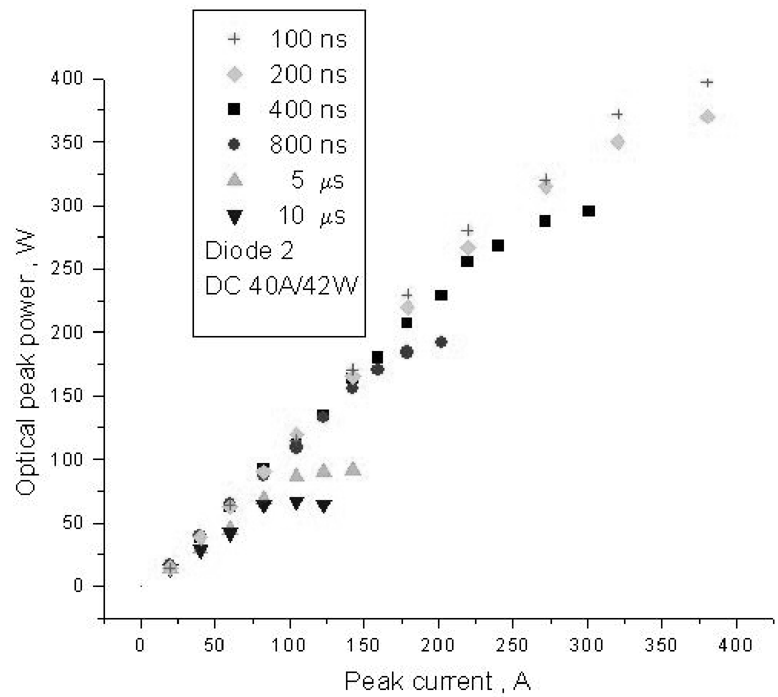

100 ns
200 ns
400 ns
800 ns
5 μs
10 μs
Diode 2
DC 40A/42W
Optical peak power , W
Peak current , A

Fig. 15 .

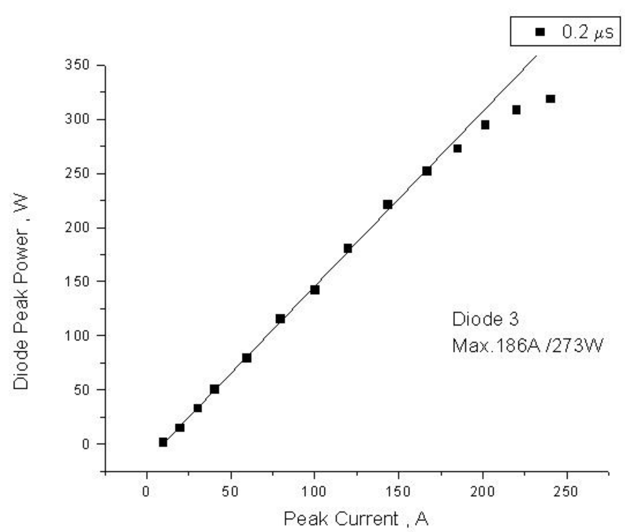

0.2 μs
Diode 3
Max.186A /273W
Diode Peak Power , W
Peak Current , A

Fig. 16 .

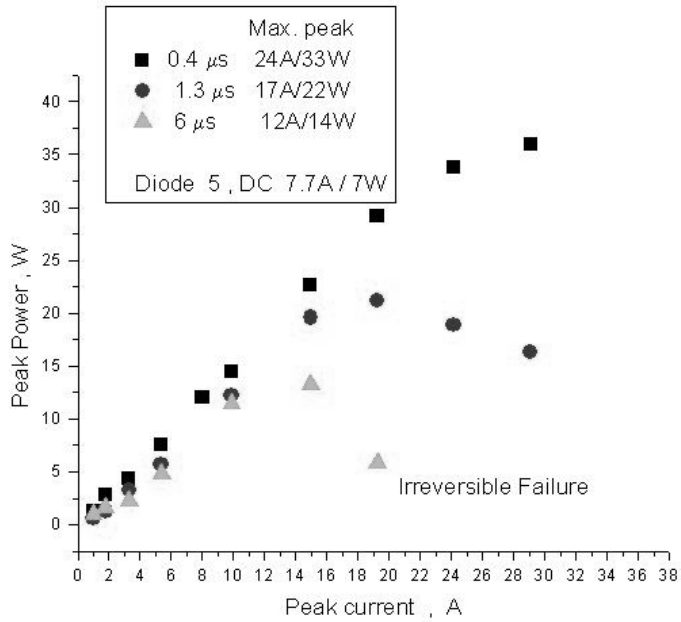


Fig. 17 .

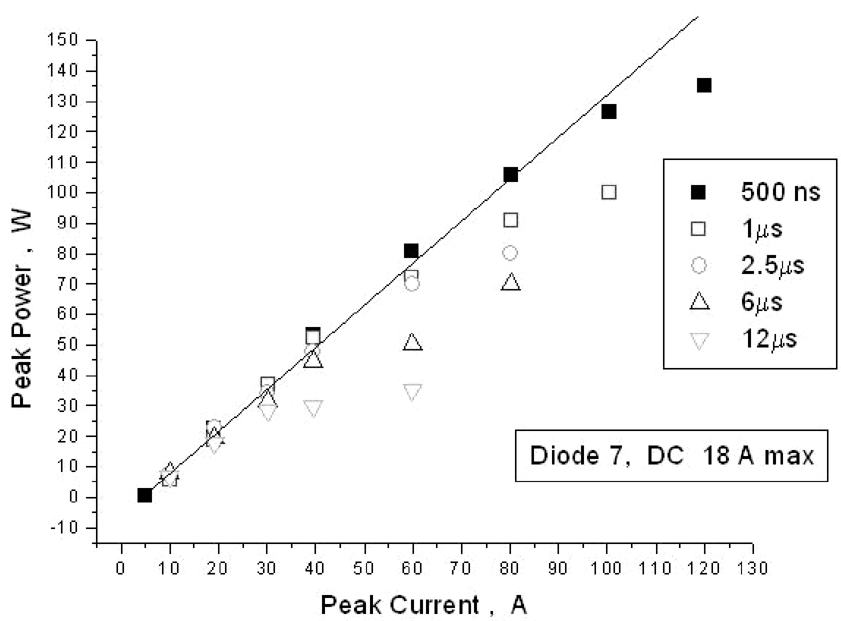


Fig. 18

The peak power is calculated for each pulse duration, assuming the rectangular shape of the current pulses. For simplicity we started from 100 ns. At shorter pulse durations the bell shape of the current pulse should be taken into account. The optical pulse, which follows the current pulse at currents much higher than the threshold current is shown on Fig. 19. for the diode 2 . The horizontal scale is 20 ns / div. The rise time is 18 ns , the fall time 25 ns. The peak value for the current is 100A. The pulse duration at FWHM is 100 ns. The temporal resolution of the p-i-n photo detector and oscilloscope is 3.5 ns . For the diodes with higher inductance the rise/fall times are longer, despite the located inside the case switch.

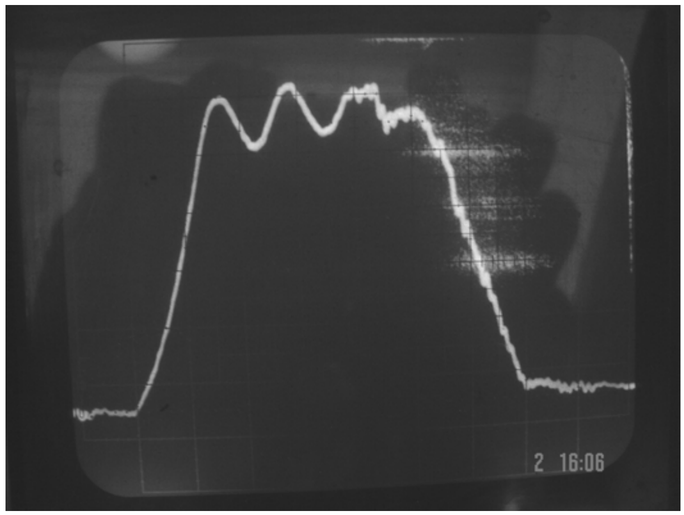


Fig. 19 .

From these data and from the thermal transient junction temperature data we may conclude that the temperature rise for shorter pulses do not restrict the maximum peak current. The maximum peak current is determined through saturation of the laser intensity mostly by impurities and non homogenious inside the laser region. The diodes , which showed irreversible failure, kept their electrical properties, the front facets were clear, but the laser threshold was increased and dark regions in the emission were observed. The diodes with non homogenious spectra and emission distribution along the fast and slow axes showed much lower maximum peak currents. Our conclusion is : the non homogenities inside the lasing region form thin channels, where the electrical current densities are much higher.

5. Optical Safety Operation Area – OpSOAR. From the data from the maximum peak currents calculated in section 4, the diagram is plotted. The diagrams for several diodes are shown on Fig. 18 – diode 1 , Fig. 19 - diode 2 , Fig. 20 - diode 5 , Fig.21 - diode 7.

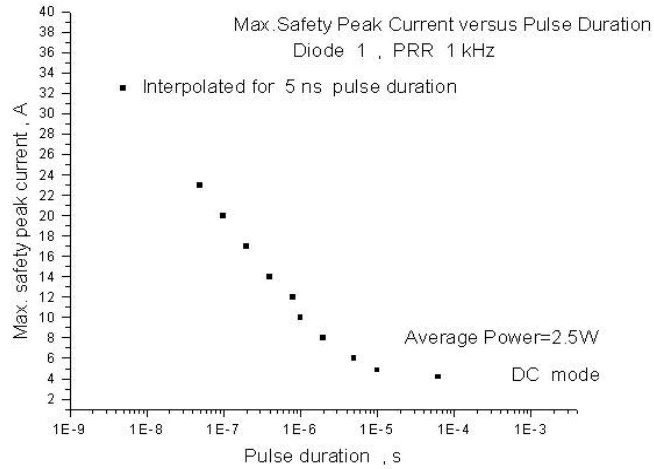

Max.Safety Peak Current versus Pulse Duration
Diode 1 , PRR 1 kHz
Interpolated for 5 ns pulse duration
Average Power=2.5W
DC mode
Max. safety peak current , A
Pulse duration , s
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
1E-9
1E-8
1E-7
1E-6
1E-5
1E-4
1E-3

Fig. 20 .

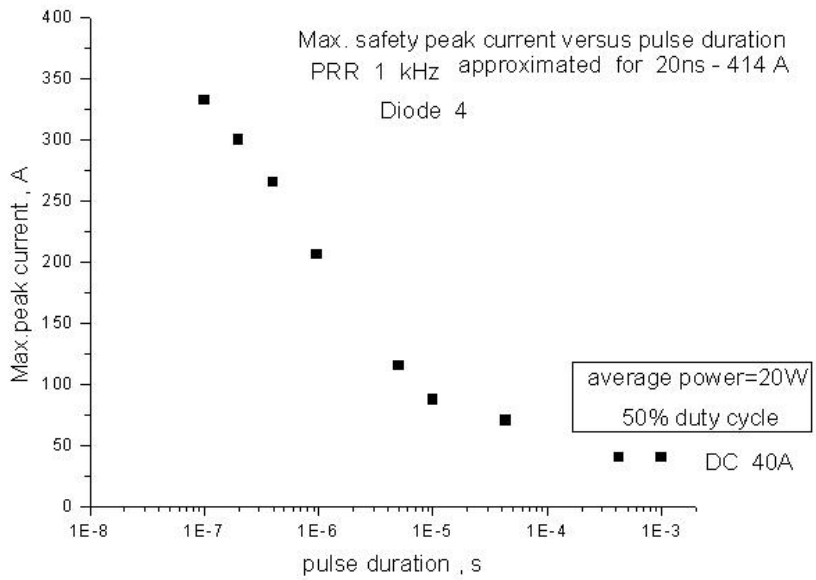
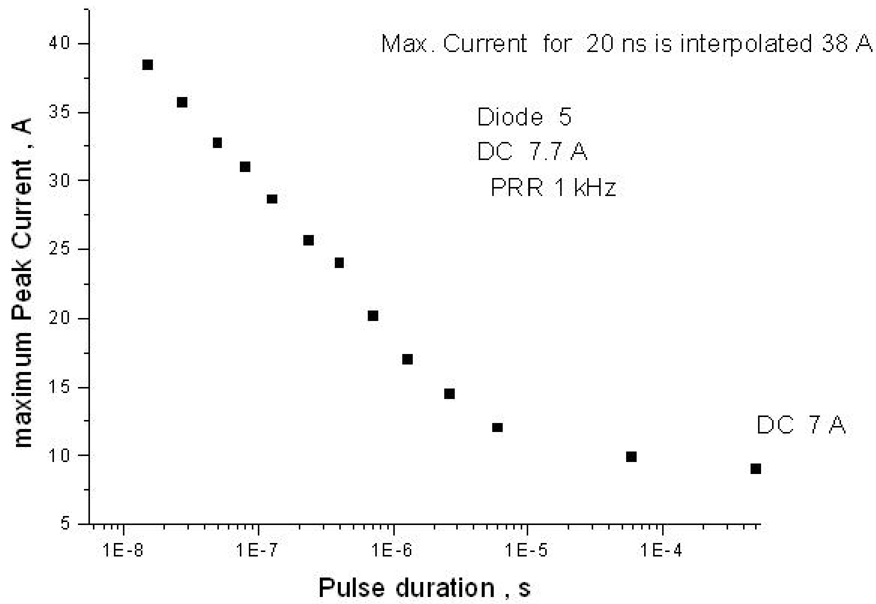
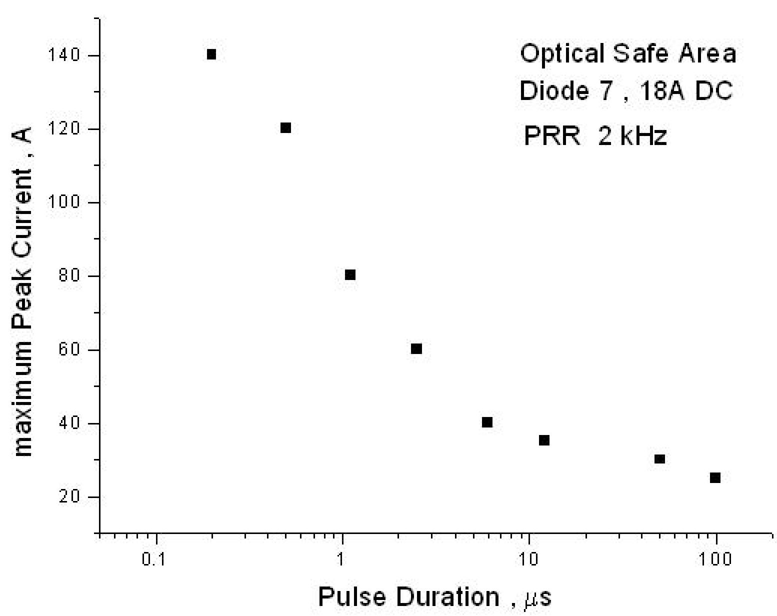

Max. safety peak current versus pulse duration
PRR 1 kHz approximated for 20ns - 414 A
Diode 4
average power=20W
50% duty cycle
DC 40A
Max.peak current , A
pulse duration , s
400
350
300
250
200
150
100
50
0
1E-8
1E-7
1E-6
1E-5
1E-4
1E-3

Fig. 21 .



Max. Current for 20 ns is interpolated 38 A
Diode 5
DC 7.7 A
PRR 1 kHz
DC 7 A
maximum Peak Current , A
40
35
30
25
20
15
10
5
1E-8
1E-7
1E-6
1E-5
1E-4
Pulse duration , s

Fig. 22 .



Optical Safe Area
Diode 7 , 18A DC
PRR 2 kHz
maximum Peak Current , A
140
120
100
80
60
40
20
0.1
1
10
100
Pulse Duration , μs

Fig. 23

We turn our attention for pulses with less than 10 μs duration, where is the interesting region. The graphs look like very similar, with the exception the ordinate axes – different currents. As we see from the data, the maximum laser diode peak current for pulses with duration shorter than 1 μs follows a logarithmic fit. After that it decrease slower till reaching the DC maximum current. Therefore we can predict the maximum value for shorter pulse duration . For pulses longer than 1 μs our data are confirmed by / 15 / .

From the data we may conclude that ns optical pulses are of practical use. There is a possibility through integrated approach of the laser diode and driving transistors on the same substrate several ns pulses with peak currents 20 times higher than the DC currents to be realized. For this a collaboration between laser diode and high power MOS elements manufactures is to be established. We see this as prolongation of the work.

6. Life time tests. In order to perform the laser diode life test we use the Arrenius approximation / 21 / for accelerated tests. Aging is empirically related to temperature equation :

$$\text{Life} = \text{At} \exp(\text{Ea}/kT)$$

where At is a constant, Ea is the activation energy, and k is the Boltzman's constant (0.86E-4 eV/K) and T is the temperature respectively. In this procedure, it is important to determine Ea accurately , due to the exponential dependence. A proper accelerated aging tests require Ea to be determined for each device in the test. This is clearly too time consuming and an average value for the population is used. This average value depends on the device structure and the material system, e.g. emission wavelength and emission aperture.

Determination of Ea generally involves at least three groups of devices each aged at a different temperature. For accuracy, twenty devices per group are required. Due to the cost and time involved, Ea is generally taken from published studies. We assume an activation energy of 0.7 eV / 20 / for the laser diode of 810 nm.

It was not so easy , as under DC mode, because the driving switch is located close to the laser diode (less inductance). It means that the switching transistors, capacitors, diodes, resistors are working at the same temperature. Therefore we redesigned the circuit to work at higher temperature. The tests were carried out for diode №1 at 75 deg.C . The diode peak current is the determined current from Fig. 18 and for 100 ns pulse duration is 20 A (the maximum DC current is 2.7 A for 2.5W power) , the repetition rate is 1 MHz . The average output optical power is measured. Important feature is that there we have two more additional parameters , pulse duration and repetition frequency, which have to kept stable during the test. The driving circuit was placed in separate thermostated box. All parameters were checked periodically. Life time is determined as a decrease of 10 % from the starting value of 2 W . The output power versus time is shown on Fig.22.

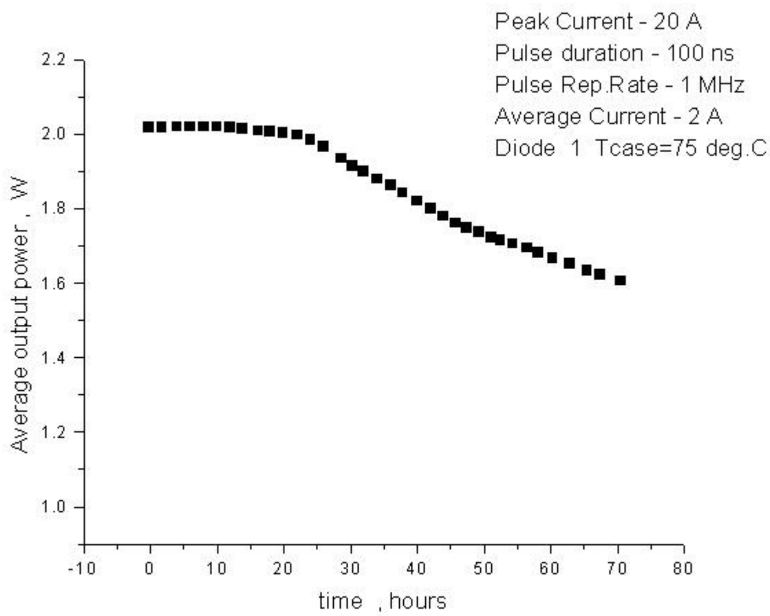


Fig. 24 .

We estimate the life time of 45 hours. That makes a life time at 20 deg.C of 4000 h approximately. If we use the industry standard of 20% output power decrease at constant current / 21 /, than the life time is 75 hours corresponding to 6 600 h at 20 deg.C . To be measured correctly the test must be performed for several diodes at different temperatures and to be compared with their life time under CW operation.

7. Discussions.

The data represent comparative study for high power laser diodes from different producers. All diodes are commercial products , without any additional requirements. It is seen that all diodes withstand safely different maximum peak currents. The maximum CW current do not have connection with the maximum peak current. The maximum peak current is determined from the saturation of the laser emission, not from thermal point of view. The reasons for irreversible failure are common for all diodes – inhomogenities in the junction structure. Therefore we can settle the following preliminary consideration for the CW diodes intended to work in pulsed mode :

Consideration for the laser diodes choice :

1. Smooth and as narrow as possible emission spectra. The irregularities in the spectra show different doping concentrations inside the heterostructure. At high peak currents they form irregularity channels, where the current densities are higher.
2. Smooth , Gaussian like spatial distribution for the fast and slow optical axes for every diode structure in the bar. This has to be measured by a slit, located close to the front facet of the laser bar. The irregularities in the spatial distribution show that inside the structure exist regions with different optical characteristics. The optical intensity inside the laser resonator reach values for nonlinear effects, which lead to very high electrical field intensity destroying the structure.
3. The specifications (Optical Safety Operation Area) must be specified for every different diode.

8. Conclusion.

A simple methodology for specifying the maximum peak currents for CW laser diodes is presented. It is shown that a CW diode may be run safely with 10 times higher peak currents. The rise / fall times of simple driving circuits may reach below several ns and the repetition rate to exceed x 10 MHz . The life time of a diode shows its possible military applications.

Several important experiments are possible to continue the work :

- Verifying the methodology for several identical diodes,
- verifying the life time through the standard industrial methodology and comparing it with the life time of the same diodes running under CW ,
- starting the project for a laser FSO communication investigations with 40 – 50 Mbit/s and distance x 10 km,
- small dimension range finder for distance x 1 km for long distance laser guided missiles

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